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A REVIEW OF THE "CHAPTERS ON THE STARS"  
BY PROFESSOR SIMON NEWCOMB, IN THE  
*POPULAR SCIENCE MONTHLY*,  
JULY, 1900,—MARCH, 1901.

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BY J. D. GALLOWAY.

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In the *Popular Science Monthly* for March of this year, there is concluded a notable contribution to the literature of popular astronomy in the "Chapters on the Stars" by Professor SIMON NEWCOMB. Professor NEWCOMB has reviewed the entire field of our knowledge of the stars, and has presented the subject with the least use of technical terms and demonstrations possible, in order to conform to the general character of the magazine in which the articles appeared. This has not, however, prevented him from dealing with the subject in the clear and lucid manner which characterizes his other works on similar subjects.

Beginning with the statements as to our knowledge of the southern heavens some thirty years ago, he traces the historical development of that work, referring especially to the history of Cordoba Observatory in the Argentine Republic, under GOULD, that of the Royal Observatory at the Cape of Good Hope, under GILL, and of the Observatory of Harvard University at Arequipa, Peru.

The development of the spectroscope is then referred to with the advancement made in the measurement of star-motions in the line of sight, originating with Sir WILLIAM HUGGINS and now being so successfully carried on by CAMPBELL. Following this, is a short discussion of the comparative dimensions of the solar system and its position among the stars.

MAGNITUDES OF THE STARS.

The second chapter deals with the magnitudes of the stars. A description of the photographic and photometric systems of measurement is given and the difficulties of both are mentioned. The magnitude of the Sun, based on the results of WOLLASTON, BOND, and ZÖLLNER is  $-26.4$ , from which it results that the Sun gives us 10,000,000,000 times the light of *Sirius*, the brightest star, and 91,000,000,000 the light of a star of magnitude one. To make our Sun shine with the intensity of the light of *Sirius*, it would be necessary to remove it to a point 100,000 times its

present distance from us. A conclusion drawn from these researches is that our Sun is smaller than the brighter of the stars.

#### CONSTELLATIONS AND STAR-NAMES.

The subject of the constellations and the names of the stars receives considerable attention. Of the constellations, the astronomical world now recognizes eighty-nine, four being counted in the subdivided constellation of *Argo* as arranged by Dr. GOULD. Considerable confusion still exists as to the boundaries of the constellations and the names of some of the stars in them. The method BAYER originated in 1601, which gives stars the names of the letters in the Greek alphabet, is followed.

#### CATALOGUING AND NUMBERING THE STARS.

A description of the method of locating the position of stars by Declination and Right Ascension is given, together with an historical review of the efforts to catalogue the stars. PTOLEMY, who lived A. D. 150, made a catalogue of 1,030 stars, but the roughness of his instruments introduced considerable error into the results. The catalogue of ARGELANDER and SCHÖNFELD, extending to  $22^{\circ}$  of South Declination, enumerates 310,000 stars, while the work as continued at the Cordoba Observatory from this point to  $42^{\circ}$  South Declination gives 340,000 more. The entire work would give more than 800,000. Photographic catalogues of the southern heavens have been made by GILL, but the work of making a photographic map of the entire heavens is now being carried out as an international enterprise, with headquarters at Paris, instruments of a uniform plan being made for the purpose. For the number of lucid stars, PICKERING gives 5,333, while SCHIAPARELLI counts 4,303. If the results of the *Durchmusterung* of Cordoba Observatory be extended to the entire sky, the number of stars down to the tenth magnitude is 2,311,000; but this is open to doubt. The international photographic chart must be completed before a correct estimate of the number of stars can be made.

#### THE SPECTRA OF THE STARS.

One of the principal branches of modern astronomy is that of spectroscopy, and considerable space is devoted to an explanation of the principles underlying the spectroscopy. Plates of the spectra of some of the larger stars accompany the text, and the chapter closes with the statement that

"the most interesting conclusion drawn from observations with the spectroscope is that the stars are composed, in the main, of elements similar to those found in our Sun. As the latter contains most of the elements found on the Earth, and few or none not found there, we may say that Earth and stars seem to be all made out of like matter. It is, however, not yet easy to say that no elements unknown on the Earth exist in the heavens. It would scarcely be safe to assume that, because the line of some terrestrial substance is found in the spectrum of a star, it is produced by that substance. It is quite possible that an unknown substance might show a line in appreciably the same position as that of some substance known to us. The evidence becomes conclusive only in the case of those elements of which the spectral lines are so numerous that when they all coincide with lines given by a star, there can be no doubt of the identity."

PROPER MOTION OF THE STARS.

The question as to the motion of the stars is answered by Professor NEWCOMB in the affirmative. In the chapter on the proper motion of the stars, he says:—

"We may assume that the stars are all in motion. It is true that only a comparatively small number of stars have been actually seen to be in motion; but as some motion exists in nearly every case where observations would permit of its being determined, we may assume the rule to be universal."

Yet this motion is very slight, and

"If HIPPARCHUS or PTOLEMY should rise from his sleep of 2,000 years — nay, if the earliest priests of Babylon should come to life again and view the heavens, they would not perceive any change to have taken place in the relative positions of the stars."

Yet the actual motions, as compared with terrestrial standards are very rapid. *Arcturus* moves from 200 to 300 miles a second, and the variation in its position can be noted in a few days, such are the refinements of modern instruments. Most of the star-motions are slower than this, ranging "from an imperceptible quantity up to 5, 10, or 20 miles a second."

The star of greatest known proper motion was discovered by KAPTEYN, of Gröningen, in 1897, co-operating with GILL and INNES, of the Cape Observatory. Rapid though its motion is, "it would require nearly 150,000 years for the star to make a complete circuit of the heavens, if it moved around the Sun uniformly at its present rate."

Groups of stars move together as one system, the *Pleiades* being an example, they having been

"found to move together with such exactness that up to the present time no difference in their proper motion has been detected."

Of motions in the line of sight, or radial motions, Professor NEWCOMB says:—

“No achievement of modern science is more remarkable than the measurement of the velocity with which the stars are moving to or from us.”

This result is obtained by the measurement of the minute difference in position of a given line in the spectrum of a moving star, as compared with the position of the same line in the spectrum formed by the same substance rendered incandescent in the tube of the telescope. This method of measurement was put in practice by Sir WILLIAM HUGGINS, and some of the best work is now being done by Professor CAMPBELL at the Lick Observatory with the Mills spectrograph.

A study of the motions of the stars by these methods has led to the discovery of the motion of the solar system, which is stated by Professor NEWCOMB thus:—

“The apex of the solar motion is in the general direction of the constellation *Lyra*, and probably very near the star *Vega*, the brightest of that constellation.”

While the data as to the rate of the Sun's motion is meager, only some fifty stars having been observed, yet KAPTEYN

“has derived results which seem to show that the actual velocity of the solar system through space is sixteen kilometers, or ten miles, per second.”

#### VARIABLE STARS.

The fact that some of the stars vary in brightness was known as early as 1596, but it was only in the early part of the nineteenth century that ARGELANDER reduced the study of the variable stars to a system. According to CHANDLER's catalogue, there are 280 of these objects which have been fairly well made out. The “new stars” which blaze out and then fade away are not included in the term “variable stars,” but those which go through a regular cycle of change in a definite interval of time. But even in periodic stars, the period is more or less variable.

“The periodic stars show wide differences, both in the length of the period and in the character of the changes they undergo. In most cases they rapidly increase in brightness during a few days or weeks, and then slowly fade away, to go through the same changes again at the end of the period. In other cases they blaze up or fade out, from time to time, like the revolving light of a lighthouse. Some stars are distinguished more especially by their maximum, or period of greatest brightness, while others are more sharply marked by minima, or periods of least

brightness. In some cases there are two unequal minima in the course of a period."

Three stars which may be seen by the naked eye illustrate the three general types of variable stars,  $\alpha$  *Ceti*, called also *Mira Ceti*,  $\beta$  *Persei*, or *Algol*, and  $\beta$  *Lyræ*.

As to the first,  $\alpha$  *Ceti*, its variations are quite irregular. Sometimes, when at its brightest, it rises nearly or quite to the second magnitude. At other times its maximum brightness scarcely exceeds the fifth magnitude. No law has been discovered by which it can be predicted whether it shall attain one degree of brightness or another at maximum. Its minima are also variable. Sometimes it sinks only to the eighth magnitude; at other times to the ninth or lower. As with other stars of this kind, it brightens up more rapidly than it fades away. The period also varies in an irregular way. As to the cause of variation,

"the most plausible view seems to be that changes of a periodic character, involving the irruption of heated matter from the interior of the body to its surface, followed by the cooling of this matter by radiation, are going on in the star."

The star *Algol*, or  $\beta$  *Persei*, is a type of the second class of variables. It is nearly of the second magnitude, but

"at intervals of somewhat less than three days, it fades away to nearly the fourth magnitude for a few hours and then slowly recovers its light."

The generally accepted explanation of the variation is that the star is double, the companion being dark and of somewhat lesser size than the bright one.

The star  $\beta$  *Lyræ* illustrates the third general class of variables. It varies nearly a degree in brightness, but the rate of variation, unlike *Algol*, is uniform. Its period is thirteen days, but there are two waves of maxima and minima, one maximum being brighter than the other. According to Professor G. W. MEYERS, of Indiana,—

"*Beta Lyræ* consists of two bodies, gaseous in their nature, which revolve around each other, so as to be almost touching. They are of unequal size. Both are self-luminous. By their mutual attraction, they are drawn into ellipsoids. The smaller body is darker than the other. When we see the two bodies laterally, they are at their brightest. As they revolve, we see them more and more end on, and thus the light diminishes. At a certain point one begins to cover the other and hide its light. Thus the combined light continues to diminish, until the two bodies move across our line of sight. Then we have a minimum. At

one minimum, however, the smaller and darker of the two bodies is projected upon the brighter one, and thus diminishes its light. At the other minimum, it is hiding behind the other, and therefore we see the light of the larger one alone."

Variable stars exist having some of the characteristics of each of these three types, so that no well-defined system of classes can be established.

#### THE DISTANCE OF THE STARS.

The distance of the Earth from the stars has always been a subject of much interest to mankind. As the stars remain fixed in direction to all ordinary observation, the conclusion has been drawn that the Earth was fixed in space. The absence of any swing deceived PTOLEMY, and was advanced as an argument against the Copernican system. Modern instruments and methods have at last detected the swing and measured it. Professor NEWCOMB enters into a detailed explanation of parallax and the history of the measurements. Several methods of measurement are used, and stars with a large proper motion are generally selected. The base line of such a measurement is the diameter of the Earth's orbit; about 184,000,000 miles. Yet with this enormous distance, it is possible to measure the parallax, or difference in direction, of but few stars. Some sixty-two have been measured, and many have been found to be without sensible parallax; in other words, the star seen from the two extremities of the Earth's orbit, appears to be in exactly the same direction. The actual distance is far beyond human conception, but it may be stated that the star *α Centauri*, with a parallax of nearly one second, is distant from us more than two hundred thousand times the distance of the Earth from the Sun.

#### BINARY AND MULTIPLE SYSTEMS.

Sir WILLIAM HERSCHEL was the first to notice that many stars which to the unaided vision seemed single were really composed of two stars in close proximity to each other. To these the general term of "double stars" is given. Only those stars which are really double are considered, those which are optically double being of no particular interest. Regarding the number of such stars, Professor NEWCOMB says:—

"With every increase of telescopic power so many closer and closer pairs are found that we cannot set any limit to the number of stars that may have companions," and "no estimate can be made of the actual number of double stars in the heavens."

"The great interest which attaches to double stars arises from the proof which they afford that the law of gravitation extends to the stars."

Where two stars revolve around a common center of gravity the term "binary system" is applied to them; yet there are systems where three or four stars form a system.

"The times of revolution of the binary systems are so long that there are only about fifty cases in which it has been determined with any certainty."

The shortest period is about eleven years.\*

"In the large majority either no motion at all has been detected or it is so slow as to indicate that the period must be several centuries, perhaps several thousand years."

Such a star is *Castor*, or a *Geminorum*. Professor SEE gives twenty-eight periods of less than one hundred years.

#### SPECTROSCOPIC BINARY SYSTEMS.

In addition to the binary systems discovered by the telescopes, the spectroscope has proved the existence of another class of double stars, usually termed "spectroscopic binary systems." Of these Professor NEWCOMB says that

"Among the many striking results of recent astronomical research, it would be difficult to name any more epoch-making than the discovery that great numbers of the stars have invisible dark bodies revolving round them of a mass comparable with their own."

The presence of the dark companion is detected by the displacement of the lines of the spectrum of the bright star. In the case of the two stars of a binary system revolving around a center of gravity, the effect produced is as if the bright body alternately advanced and receded. This would result in a displacement of the spectral lines, first to one side and then to the other, of the normal position of the body at rest. The spectroscopic binary systems are very close as regards the distance between the components, and a gap exists between them and the telescopic binary systems, which is being filled as our telescopes increase in power.

"We naturally infer that there is no limit to the proximity of the pairs of stars of such systems, and that innumerable stars may have satellites, planets, or companion stars so close or so faint as to elude our powers of observation."

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\*See, however, Professor HUSSEY's orbit of  $\delta$  *Equulei* in No. 76 of these *Publications*.

## STAR CLUSTERS.

Other interesting features of the heavens are the star clusters. Faint patches of light as seen by the eye are resolved by the telescope into masses of bright stars.

“In many cases the central portions of these objects are so condensed that they cannot be visually resolved into their separate stars, even with the most powerful telescopes.” “The most remarkable and suggestive feature of the principal clusters is the number of variable stars which they contain. The richest in variables is *Messier 3*, in which one variable has been detected among every seven stars. . . . Very remarkable, at least in the case of  $\omega$  *Centauri*, is the shortness of the period of the variables. Out of one hundred and twenty-five found, ninety-eight have periods less than twenty-four hours, . . . the range in brightness being two magnitudes.”

“Perhaps the most important problem connected with clusters is the mutual gravitation of their component stars. Where thousands of stars are condensed into a space so small, what prevents them from all falling together into one confused mass? Are they really doing so, and will they ultimately form a single body? These are questions which can be satisfactorily answered only by centuries of observation; they must, therefore, be left to the astronomers of the future.”

## NEBULÆ.

The nebulæ, which exist in different parts of the sky, form another very impressive subject for study. Some few, as the Great Nebula in *Orion*, may be seen by the naked eye. They are of many forms, but in a majority the spiral shape has been found. Some are in the form of rings, as the one in *Lyra*. Others seem to be scattered in space without form, the nebulous mass in *Cygnus* being an example. Others have the form of discs, and are called “planetary nebulæ.”

“It is impossible to estimate the number of nebulæ in the heavens. . . . KEELER estimated the whole number to be several hundred thousand . . . A curious fact connected with the distribution of nebulæ over the sky is that it is, in a certain sense, the reverse of the stars. The latter are vastly more numerous in the regions near the Milky Way and fewer in number near the poles of that belt. But the reverse is the case with the nebulæ proper. . . . Perhaps the most obvious suggestion would be that in these two opposite nebulous regions the nebulæ have not yet condensed into stars. This, however, would be a purely speculative explanation.”

“The most interesting question connected with these objects is that of their physical constitution. HUGGINS and SECCHI found independently that the light of the Great Nebula in *Orion* formed a spectrum of bright lines, thus showing the object to be gaseous.”

"This was soon found to be true of nebulae in general, that in *Andromeda* being an exception, as it gives a more or less continuous spectrum."

"Beyond the general fact that the light of a nebula does not come from solid matter, but from matter of a gaseous or other attenuated form, we have no certain knowledge of the physical constitution of these bodies."

The spectrum of a great number shows a bright line "which does not correspond to the line of any known substance. The supposed matter which produces it has, therefore, been called *nebulium*." Another conclusion based on their immense dimensions is that they are of extreme tenuity.

#### MASSES AND DENSITIES OF THE STARS.

Closely connected with the different phenomena to be seen in the heavens lies the question of the size of the stars.

"The spectroscope shows that, although the constitution of the stars offers an infinite variety of detail, we may say, in a general way, that these bodies are suns. It would perhaps be more correct to say that the Sun is one of the stars and does not differ essentially from them in constitution. The problem of the physical constitution of the Sun and stars may, therefore, be regarded as the same. Both consist of vast masses of incandescent matter at so exalted a temperature as to shine by their own light. All may be regarded as bodies of the same general nature. . . . In a few cases an approximate estimate of the density of the stars may be made."

These are binary stars whose parallax or distance from us is known.

"But there is a remarkable law which, so far as I know, was first announced by PICKERING, by virtue of which we can determine a certain relation between the surface brilliancy and the density of a binary system without knowing its parallax."

Here follows a demonstration which space will not permit following, but the conclusion arrived at is that

"the stars in general are not models of our Sun, but have a much smaller mass in proportion to the light they give than our Sun has. They must, therefore, have either a less density or a greater surface brilliancy. . . . Many of them are probably even less dense than air, and in nearly all cases the density is far less than that of any known liquid."

It follows that at least the brighter stars are masses of gas, more or less compressed in their interior by the action of gravitation upon their more superficial parts.

"This conclusion was arrived at, at least in the case of the Sun, from different considerations before the spectroscope had taught us anything of the constitution of the bodies.

## SOURCE OF THE SUN'S HEAT.

It is accepted that for untold millions of years, the Sun has been radiating heat into space, and the problem has been to discover the source of the heat. In the time of KANT, NEWTON, LAPLACE, and HERSCHEL, no reason was known why the stars should not shine on forever without change. Now that heat has been determined as a form of energy, the supply of which is limited, it becomes a question as to the source of supply. If the Sun, composed, as it is known to be, of the same material as the Earth, kept on radiating its heat as it does without a source of supply, it would cool off at the rate of from  $5^{\circ}$  to  $10^{\circ}$  a year. The theory of meteors falling to the Sun was advanced, but this has been abandoned for the theory of KELVIN and HELMHOLTZ, that the source of the heat is the contraction of the material of the Sun, calculated as 200 feet a year, or four miles in a century. From this it follows that the Sun must be a gas, for

“if solid, the exterior would rapidly cool off, since the heat would have to be conducted from the interior. Then, the loss of heat no longer going on at the same rate, the contraction also would stop and the generation of heat to supply the radiation would cease. Even were the Sun a liquid, currents of liquid matter could scarcely convey to the surface a sufficient amount of heated matter to supply the enormous radiation.”

The fact that the Sun remains gaseous at the extreme density, more than that of water, is explained by the compression of the interior by the weight of the outside portions.

The theory developed by RITTER regarding the source of heat being due to the contraction of the volume of the Sun has for a basis the paradoxical law announced by LANE, that

“When a spherical mass of incandescent gas contracts through the loss of its heat by radiation into space, its temperature continually becomes higher as long as the gaseous condition is retained.”

## STELLAR EVOLUTION.

On this is based the theory of stellar evolution. We may start with the nebulæ, when, by some progressive change, they began to shine. This is the unsolvable question: How did they begin? The gradual contraction under gravity resulted in a gaseous body of a higher temperature. It is thus possible to speak of the age of a star, meaning periods measured by tens of millions or hundreds of millions of years. Sir WILLIAM HUGGINS gives the series of ages based on the color of light emitted,

which starting with bluish-white at the first stage, passes on through white into yellow and red. The series is as follows:—

<i>Sirius, α Lyræ.</i>	<i>α Cygni.</i>
<i>α Ursæ Majoris.</i>	<i>Capella</i> — The Sun.
<i>α Virginis.</i>	<i>Arcturus.</i>
<i>α Aquilæ.</i>	<i>Aldebaran.</i>
<i>Rigel.</i>	<i>α Orionis.</i>

A question of interest is, At what stage will the temperature reach its maximum? It is impossible to give a precise answer, but “it seems probable that the highest temperature is reached in about the stage of our Sun.”

While the indications point to the truth of this theory,

“Yet there are some unsolved mysteries connected with the case, which might justify a waiting for further evidence, coupled with a certain degree of skepticism.”

The nebulae offer a difficulty. Their extreme tenuity and their seemingly almost immaterial structure appear inadequate to account for any such mutual gravitation of their parts as would result in the generation of the flood of energy they are constantly radiating. We must therefore suggest at least the possibility that all shining heavenly bodies have connected with them some form of energy of which science can, as yet, render no account.”

#### STRUCTURE OF THE STELLAR UNIVERSE.

From the discussion of the origin of the stellar universe, Professor NEWCOMB passes to its structure.

“The problem of the structure and duration of the universe is the most far-reaching with which the mind has to deal. Its solution may be regarded as the ultimate object of stellar astronomy. . . . Although we can attack the problem to-day by scientific methods, to a limited extent, it must be admitted that we have scarcely taken more than the first step toward the actual solution.

“Firstly, we may inquire as to the extent of the universe of stars. Are the latter scattered through infinite space, so that those we see are merely that portion of an infinite collection which happens to be within reach of our telescopes, or are all the stars contained within a certain limited space? In the latter case, have our telescopes yet penetrated to the boundary in any direction?

“Secondly, granting the universe to be finite, what is the arrangement of the stars in space? In what sense, if any, can the stars be said to form a permanent system? Do the stars which form the Milky Way belong to a different system from the other stars, or are the latter a part of one universal system?

“Thirdly, what is the duration of the universe in time? Is it fitted to last forever in its present form, or does it contain within itself the

seeds of dissolution? Must it, in the course of time, in we know not how many millions of ages, be transformed into something very different from what it now is?"

The first and third propositions were, according to KANT, equally susceptible of proof or disproof from *à priori* reasoning. The scientific man objects to this conclusion, as the propositions are matters of fact. The more correct view is that of Sir WILLIAM HAMILTON, that the conception of infinite space or time, or the coming to an end of space or time, is impossible for us to hold, the deficiency being due to our mental limitations. So this gives us no clew to the actual universe. Our conclusions must be based on actual observation.

#### EXTENT OF THE UNIVERSE.

There is a law of optics which throws some light on the question of the extent of the universe. If we assume the stars uniformly distributed throughout space and conceive a number of spherical shells, one outside of another, extended indefinitely, then the number of stars in each spherical shell would be proportional to the square of the radius of the given shell. But the light from the shells varies inversely as the square of the distance from the center where the observer is; therefore each successive shell would send equal amounts of light to the center. In this case if the universe was indefinitely extended, the "heavens would be filled with a blaze of light as bright as the Sun."

"But there are two limitations to this conclusion. It rests upon the hypothesis that light is never lost in its passage to any distance however great. This hypothesis is in accordance with our modern theories of physics, yet it cannot be regarded as an established fact for all space, even if it be true for the distances of the visible stars."

Again, an infinite universe could be imagined on the hypothesis of LAMBERT. A number of groups like the solar form a greater system, and a number of these systems form the Galaxy.

"But modern developments show that there is no scientific basis for this conception, attractive though it is by its grandeur."

"So far as our present light goes, we must conclude that, although we are unable to set absolute bounds to the universe, yet the great mass of stars is included within a limited space, of whose extent we have as yet no evidence. Outside of this space there may be scattered stars or invisible systems. But if these systems exist, they are distinct from our own."

#### THE ARRANGEMENT OF THE STARS IN SPACE.

"The second question, that of the arrangement of the stars in space, is one on which it is equally difficult to propound a definite general conclu-

sion. . . . Sir WILLIAM HERSCHEL reached the conclusion that our universe was a comparatively thin but widely extended stratum of stars. But we cannot assume that this hypothesis of the form of the universe affords the basis for a satisfactory conception of the arrangement."

The Milky Way would be uniformly illumined, but it is not, being a chain of irregular, cloudlike aggregations of stars. Professor NEWCOMB then enters into a discussion of the appearance of a universe of stars in the form of a circular disc as seen from different directions. Following this is a summary of observed data bearing on the distribution of the stars, the results of which are as follows. The lucid stars increase in density toward the Milky Way, so that if

"the cloudlike forms which make up the Milky Way were invisible to us, we should still be able to mark its course by the condensation of the brighter stars."

Of the fainter stars,—

"the star density in the several regions increases continuously from each pole to the Galaxy itself. . . . The conclusion to be drawn is a fundamental one. The universe, or, at least, the denser portions of it, is really flattened between the galactic poles, as supposed by HERSCHEL and STRUVE."

As to those stars having a proper motion, the following is advanced:—

"Having found that the stars of every magnitude have a tendency to crowd toward the region of the Milky Way, the question arises whether this is true of those stars which have a sensible proper motion. KAPTEYN has examined this question in the case of the Bradley stars. His conclusion is that those having a considerable proper motion, say more than ten seconds per century, are nearly equally distributed over the sky, but that when we include those having a small proper motion, we see a continually increasing tendency to crowd toward the galactic plane. The conclusion is interesting and important. If we should blot out from the sky all the stars having no proper motion large enough to be detected, we should find remaining stars of all magnitudes; but they would be scattered almost uniformly over the sky, and show no tendency toward the Galaxy."

"From this it again follows that the stars belonging to the Galaxy lie farther away than those whose proper motions can be detected."

A study of the heavens will soon show that there is a tendency for the bright lucid stars to form groups, instances of which are the *Pleiades*, *Præsepe*, and *Orion*.

"The question we now propose to consider is whether these clusters include within their limits an important number of the small stars seen in the same direction. If they and all the small stars which they con-

tain within their actual limits were removed from the sky, would important gaps be left? The significance of this question will be readily seen. If important gaps would be left, it would follow that a large proportion of the stars which we see in the direction of the clusters really belong to the latter, and that, therefore, most of the stars would be contained within a limited region."

After a numerical examination of the number of stars within the groups mentioned above, the conclusion is that

"the agglomeration of the lucid stars into clusters does not, in the cases where it is noticeable to the eye, extend to the fainter stars."

A study of the regions relatively poor in lucid stars leads to the same conclusion.

#### THE MILKY WAY.

Passing now to the structure of the Milky Way, Professor NEWCOMB gives a detailed description of the wonderful object as seen by an observer at different times of the year. One of the first noted facts is the inequalities of structure, which are noticeable to the eye.

"The Milky Way is something more than the result of the general tendency of the stars to increase in number as we approach its central line. There must be large local aggregations of stars, because, as we have already pointed out, there cannot be such diversity of structure shown in a view of a very widely stretched stratum of stars. . . . The fundamental question we meet in our further study of this subject is: At what magnitude do these agglomerations of stars begin? Admitting, as we must, that they are local, are they composed altogether of stars so distant as to be faint, or do they include stars of considerable brightness?"

A method of counting the stars in the regions in question, is followed, and

"The conclusion is that an important fraction of the lucid stars which we see in the same areas with the agglomerations of the Milky Way is really in those agglomerations and forms part of them."

The darker regions of the Milky Way are also found to contain as many stars as there are in the regions immediately on each side of the galactic belt. The evidence is that

"separate from the accumulations of stars in the Milky Way, perhaps extending beyond them, there is a vast collection of scattered stars, spread out in the direction of the galactic plane, which fill the celestial spaces in every direction. We have shown that when, from any one area of the sky, we abstract the stars contained in clusters, this great mass is not seriously diminished. We have also collected evidence that the distances of this great mass are very unequal; in other words, there is no great accumulation, in a superficial layer, at some one distance. . . .

Our general conclusion is this: If we remove from the sky all the local aggregations of stars, and also the entire collection which forms the Milky Way, we should have left a scattered collection, constantly increasing in density toward the galactic belt."

Another interesting point to be considered is the increasing number of stars with diminishing brightness. The number of stars in each succeeding order of magnitude is between three and four times as great as in the preceding one. Using only rough approximations, the amount of light received will be about doubled for a change of two units of magnitude, the stars of lower magnitude, though fainter individually, being greater in number, collectively give more light. A careful summary of the star catalogues leads to the general conclusion that

"up to the eleventh magnitude there is no marked falling off in the ratio of increase, even near the poles of the Galaxy."

The question when the series begins to fall away is, therefore, still an undecided one. If there be no diminution of light due to distance, then the number of stars must begin to decrease at some point, or the sky would be filled with a blaze of light.

"From what has been shown of the total amount of light received from stars of the smaller magnitudes, it would seem certain that a considerable fraction of the apparently smooth and uniform light of the sky may come from these countless telescopic stars, even perhaps from those which are not found on the most delicate photographs."

The chapter following is devoted to a statistical study of the proper motions of the stars. Space will not permit us to follow Professor NEWCOMB in his argument on this subject. His general conclusion, which he says is in good agreement with that arrived at by Professor KAPTEYN by a different method, is that the average actual motion of a star in space is about 37 kilometers per second. The motion of Sun is given as 20 kilometers. The Sun is therefore a star of quite small proper motion.

#### DISTRIBUTION OF THE STARS IN SPACE.

In the final chapter, on the distribution of the stars in space, the lines of thought set forth in the former chapters are made to converge on that main and concluding problem. With our system as a center, the celestial space is supposed divided into concentric shells, the radius of the first inside sphere being equal to 206.265 times the orbit of the Earth, or a distance at which the parallax of a star would be 1". The succeeding shells have radii of 2 R, 3 R, etc., and the parallaxes of the stars on the

surface would be respectively  $0''.5$ ,  $0''.33$ ,  $0''.25$ , etc. In the first sphere, since no star has been found with a parallax of  $1''$ , the Sun would be alone. Continuing, a list is given of the stars whose parallax is known, and the result is that in the second sphere there would be one star to seven units of space of the cube of  $R$ . The outer regions give the ratio of one in twelve. Considering the first result, there would be one star in a sphere of radius  $R$ , or diameter 412,500 times the Earth's orbit. Light traveling over 180,000 miles a second would thus pass a star every eight and a half years. A study of the large and small proper motions leads to about the same conclusion, or one star to eight units of space of the cube of  $R$ . By a study of the stars with a cross motion of less than  $2''.5$  per century, it is concluded that the sphere of lucid stars extends much beyond 400  $R$ .

"Granting the star density as we have supposed, a sphere of radius 400  $R$  would contain 8,000,000 stars. As we see more than this number with our telescope, we have no reason to suppose the boundary of the stellar system, if boundary it has, to be anywhere near this limit."

"All the facts we have collected lead to the belief that, out to a certain distance, the stars are scattered without any great and well-marked deviation from uniformity. But the phenomena of the Milky Way show that there is a distance at which this ceases to be true. . . . Can we form any idea where this difference begins, or what is the nearest sphere which will contain an important number of galactic stars? A precise idea, no; a vague one, yes. We have seen that the galactic agglomerations contain quite a number of lucid stars, and that, perhaps, an eighth of these stars are outside the sphere 400  $R$ . We may, therefore, infer that the Milky Way stars lie not immensely outside this sphere. More than this, it does not seem possible to say at present."

It is probable that we lie near the center of the stellar universe. The equality of the stars on both sides of the galactic circle and the fact that the galactic circle is a great circle are offered as proof. This merely proves that we lie in the galactic plane. The evidence as to our lying near the center is not so conclusive, and not until the international photographic survey of the heavens is completed does it seem possible to reach a more definite conclusion.

Inspired by that spirit of caution which characterizes the entire series of chapters when dealing with conclusions not entirely supported by facts, Professor NEWCOMB closes thus:—

"One reflection may occur to the thinking reader as he sees the reasons for deeming our position in the universe to be the central one. PROBLEMY showed by evidence, which, from his standpoint, looked as sound as that we have cited, that the Earth was fixed in the center of the universe. May we not be the victims of some fallacy, as he was?"